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Evaluation of Land Use/Land Cover Change with Time in Assessing Soil Erosion Risk in Isiukhu River Catchment, Kakamega County, Kenya

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Abstract

An evaluation of land use/land cover (LULC) change with time in assessing soil erosion risk is essential in soil conservation and environmental management. Land use/land cover management factor (C) plays crucial role in determination of soil loss and thus affects agricultural production. Land use/land cover is influenced by anthropogenic activities. Isiukhu river catchment and its environs have experienced fatal landslides leading to loss of lives and property. Land use/land cover change between 1990 and 2015 was determined in ArcGIS 10.3 environment. Soil erosion risk was determined by applying revised universal soil loss equation (RUSLE) model in ArcGIS 10.3. The LULC changed with time, in 1990 weighted mean of C factor was 0.051 and in 2015 was 0.344. The soil erosion risk was influenced by change in LULC, in 1990 weighted mean ($RUSLE_{weighted\ mean}$) was 7.2 t/ha/y and 85% of the catchment was within soil loss tolerance limit (12t/ha/y), and in 2015 weighted mean (RUSLEweighted mean) was 32 t/ha/y and only 3% of the catchment was within tolerance limit. This could be due to degradation of natural cover within the catchment. Deforestation as a result of farming activities and settlement in the catchment forest could have led to exposure of ground to surface run-off. The high rate of soil erosion could be reduced by controlling encroachment on the forest, proper land use/land cover through multiple-cropping and implementation of soil erosion control support practices.

Keywords: Land use/land cover change; soil erosion risk; years; RUSLE; GIS; Isiukhu river catchment; Kenya.

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1. Introduction

1.1 Background

Globally soil erosion is one of the global environmental problems resulting in both on-site and off-site effects on catchments. Soil erosion, defined as the detachment, transportation and deposition of soil particles by wind or water, is a natural process driven by physical factors [1]. The intensity of erosion processes depends on soil properties, topography and vegetation cover. The author in [2] stated that soil erosion leads to environmental degradation that is a precursor to disaster risks such as landslides, loss of soil fertility and infrastructure destruction The economic implications of soil erosion are more serious in developing countries because of lack of capacity to cope with it and also to replace lost nutrients. These countries also have high population growth which leads to intensified use of already stressed resources and expansion of production to marginal and fragile lands. Such processes aggravate erosion and productivity declines, resulting in a population-poverty-land degradation cycle [3]. In Kenya, agriculture is the backbone of the country’s economy. Good soils lead to increased agricultural production. Studies carried out on soil erosion risk in Kenya show that more than 75% of Kenya’s soil is fragile environmentally. Soil erosion in Kenya leads to land degradation that lowers its capability to produce and increases its vulnerability to disaster hazards [4]. Farmers’ knowledge on soil erosion hazards is very crucial in sustaining Kenya’s agricultural production [5]. The anthropogenic pressure on land in Kenya is essentially reflected in the land cover, where land use change and -intensity and cultivation practices, such as tillage and implementation of conservation strategies, determine the vulnerability to erosion [6]. Isiukhu River has its source in Nandi escarpment, Nandi forest on the boundary of Nandi and Kakamega Counties. It combines with river Lusumu before draining in river Nzoia in Mumias Sub-County. Isiukhu river catchment has had a lot of environmental challenges emanating from deforestation and improper conservation measures [7]. Mono-cropping of maize and sugarcane on majority of the farms in the catchment poses serious environmental challenges including landslides that occurred at Khuvasali village in August 2007 killing 12 people, injuring100 and displacing 49 families and another one at Chepng’abai hills in May 2016 that killed one mother and her four children [7, 8]. Technologies to counteract fertility constraints are rarely implemented, as they do not consider system diversity or farm-specific characteristics [9]. Land use/land cover factor (C) is the cover management parameter and it ranges between 0 (ideal case when there is no soil loss) and 1, corresponding to the greater amount of soil loss. This dimensionless factor measures the ratio of soil loss between a specific area with given cover management conditions and an experimental plot under reference conditions "clean tilled continuous fallow conditions"[10]. As management-cover situations can vary a lot from one place to another, a sub factor approach to estimate C values was proposed in the Revised Universal Soil Loss Equation, [11]. According to the author in [12], the process for determining soil erosion must involve identifying the factors that control the risk of erosion, use parameters for which data are available for the particular region, can be adjusted easily as more/better information becomes available, and is a method that has been vetted in the published literature. A number of models have been developed to predict soil erosion risk at various scales from individual fields to entire drainage basins. Each model requires specific information in order to predict soil erosion risk. This information is not available for Isiukhu river catchment. It is with the foregoing in mind that this research sought to fulfill its objective of evaluating land use/land cover change with time in assessing soil erosion risk in Isiukhu river catchment. The study employed RUSLE model in ArcGIS 10.3 in determining land use/land cover change with time and in assessing soil erosion risk.

1.2 Constraints\Limitations of the study

The environmental variables used in RUSLE model are relatively constant over the timescale of tens of years (at a minimum), while the management variables may change over the course of a year or less. Consequently, it is difficult to obtain current and accurate management variable coverage [11]. Several algorithms are required when processing data for input into RUSLE model used in this study. Each of those algorithms may accentuate existing errors in data. Because RUSLE requires five input data layers to be overlaid in ArcGIS, the errors inherent in each layer are similarly multiplied, contributing to an even greater error in the derived soil loss values [13]. The erosion processes which are considered by RUSLE model in this study are often driven by relatively small features. Therefore, any output should be treated as qualitative, not quantitative, and the pattern of erosion, or vulnerability, should be examined [14]

2. Materials and methods

2.1 Study site

Isiukhu river catchment lies in Kakamega County, Western region of Kenya Its geographical coordinates are: 0° 15' 0" – 0^o 25' 0" North and 34° 40' 0" - 34° 55' 0" East (Figure 1). The study area covers an area of approximately 683.0 Km^2 (68,300ha) with an approximate population of 373,600. The altitudes of the study area range from 1,317 metres above sea level to 2,144 metres above sea level. There are two main ecological zones in the catchment namely; the Upper Medium (UM) and the Lower Medium (LM). The Upper Medium in which Nandi escarpment lies covers the Central and Northern parts of the county such as Lurambi, Malava, Shinyalu and Ikolomani that practise intensive maize, beans and horticultural production mainly on small scale; and Lugari and Likuyani where large scale farming is practiced. The second ecological zone, the Lower Medium (LM), covers a major portion of the southern part of the county which includes Mumias, Matungu and Butere and Khwisero. In this zone, the main economic activity is sugarcane and maize production with some farmers practicing sweet potatoes, tea, ground nuts and cassava production.

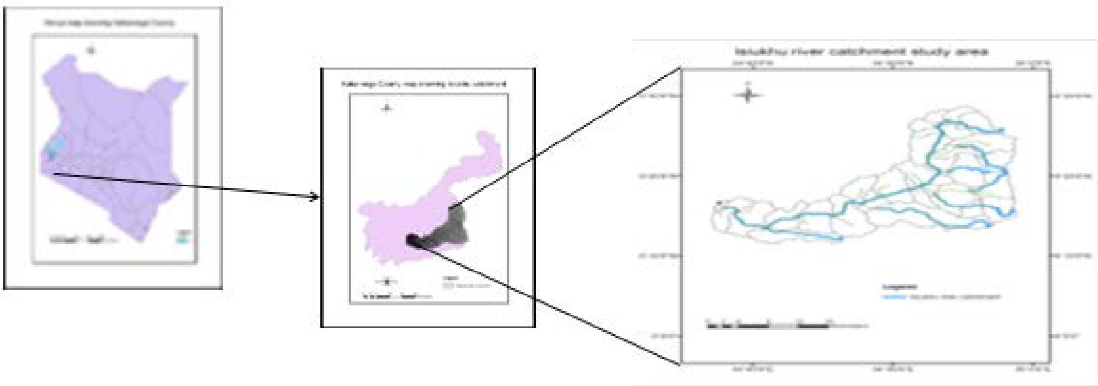

Figure 1: Location of the study site

2.2 Data collection and processing

Meteorological data—monthly and annual precipitation data from available rainfall stations serving Isiukhu river catchment – Malava forest, Mundoli, Kakamega Met. Station, Mumias sugar, Bukura ATC and Alupe KALRO. Soil and Terrain (SOTER) map - vector data set from international soil reference and information centre (ISRIC) world soil information for Kenya soil DataBase set (KENSOTER). Digital Elevation Model (DEM) of 30m resolution—reference data set from Kakamega County Survey Office, based on the photogrammetric workout in the form of a Triangulated Irregular Network (TIN) having a vertical accuracy to the tens of centimeters. Figure 2 shows data collection and processing.

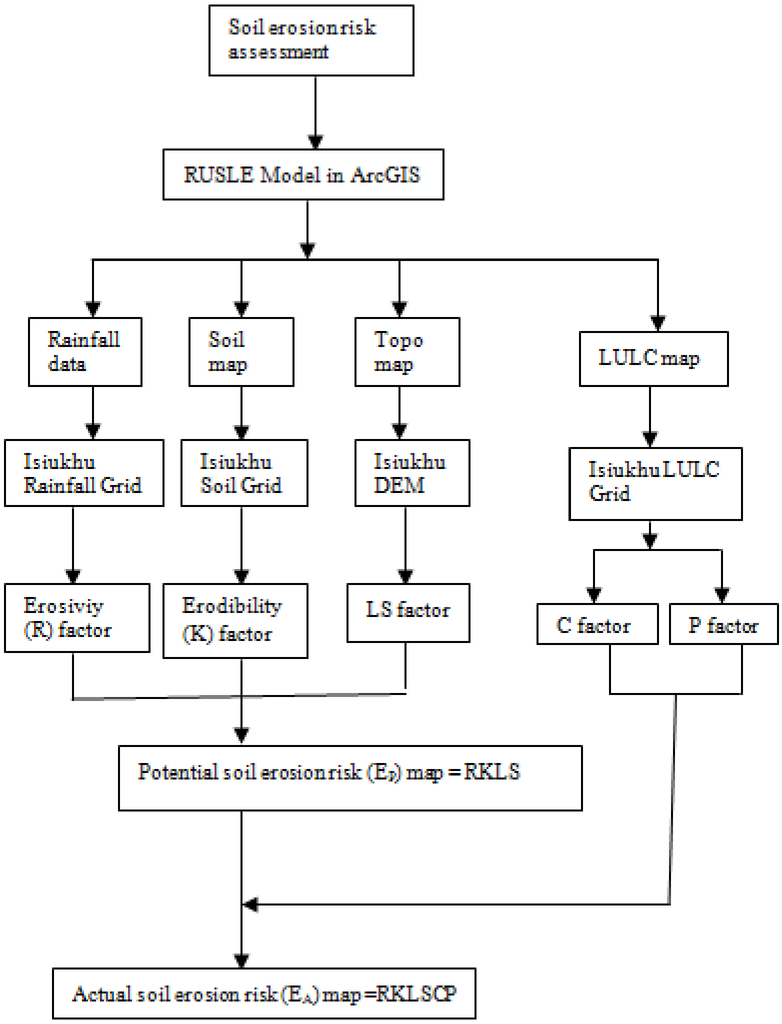

Figure 2: Methodology flow chart

2.3 Computation of Rainfall Erosivity Factor (R)

The rainfall erosivity factor (R) was calculated from equation (1) [15]

$$F_M = \sum_{i=1}^{12} \frac{P_i^2}{P} \qquad (1)$$

where: $F_M =$ Modified Fournier Index, $P_i =$ the monthly average amount of precipitation for month i (mm), and $P =$ the average annual quantity of precipitation (mm).

Plotting Fm index values in mm (Y - axis) against rainfall station altitudes in metres (X – axis) generated equation (2) which was used in ArcGIS 10.3 to compute rainfall erosivity factor (R) map.

$$Y = -0.0144X + 194.29 \qquad (2)$$

where: Y = Modified Fournier Index in mm, X = Study area DEM

2.4 Computation of soil erodibility factor (K)

For this study, K factor was generated from the soil shapefile map of the Isiukhu study area. Kenya soil database was used to produce the soil shapefile for the study area. The soil map was overlaid in ArcGiS. It was given spatial reference which was the same as the study area (WGS 1984 UTM Zone 37N). The study area was then clipped from the rest of the soil map feature and attribute table of the study area was edited for K factor before it was changed to raster file to give K factor map and its values.

2.5 Computation of slope length and slope steepness factor (LS)

LS factor was calculated from equation (3) [16]

$$LS = \left(\frac{x}{22.13}\right)^m (0.065 + 0.045s + 0.065s^2) \qquad (3)$$

where:

x – Slope length (m)

s – Slope gradient (%)

The values of x and s were derived from study area Digital Elevation Model (DEM). To calculate the x value, Flow Accumulation was derived from the DEM after conducting Fill and Flow Direction processes in ArcGIS 10.3.

Hence x=Flow accumulation *cell value as in equation (4). Equation (4) was applied in ArcGIS 10.3 to generate LS factor map

$$LS = \left(\frac{Flowaccumulation \times cellvalue}{22.13} \right)^{m}$$
$$(0.065 + 0.045s + 0.065s^{2})equation \qquad (4)$$

2.6 Computation of Cover management (C) factor for 1990, 2000, 2010 and 2015

For this study, C factors for 1990, 2000, 2010 and 2015 were generated from the Land use/land cover shapefile map of the Isiukhu study area. Kenya soil database from world soil information of international soil reference and information centre (ISRIC) was used to produce the soil shapefile for the study area. The land use/land cover map was overlaid in ArcGiS. It was given spatial reference which was the same as the study area (WGS 1984 UTM Zone 37N). The study area was then clipped from the rest of the land use map feature. The land use/land cover map attribute table of the soil map of study area of each year (1990, 2000, 2010 and 2015) was edited with adding a new field of C factor values under the Edit menu at attribute view. Then under conversion in spatial analyst the feature (Isiukhu land use shapefile) using C factor as the field it was converted to Raster. The C factor used for different land use composition was tabulated.

2.7 Computation of soil erosion control support practice (P) factor

In this study, Fall's equation (5) was used in ArcGIS 10.3 environment to compute P factor values

$$P = (Fac) * 0.45249^{0.6} + (0.01745 * Slope\_\deg ree) \qquad (5)$$

where; P is practice factor; Fac = Study area DEM flow accumulation; Slope_degree = Study area DEM slope in degrees.

As the first step, the elevation value was modified by filling the sinks in the grid. This is done to avoid the problem of discontinuous flow when water is trapped in a cell, which is surrounded by cells with higher elevation. This was done by using the Fill tool under Hydrology section found under Spatial Analyst Tool Function in ArcGIS. Then, Flow direction was generated from the Fill grid. The Flow direction tool takes a terrain surface and identifies the down-slope direction for each cell. This grid shows the on surface water flow direction from one cell to one of the eight neighboring cells. This was done by using the Flow direction tool under Hydrology section found under Spatial Analyst Tool Function in ArcGIS

3. Results

3.1 Rainfall erosivity factor (R)

Rainfall erosivity factor (R) values ranged from 163 MJmmha-^{1}h^{-1}yr^{-1} to 175 MJmmha-^{1}h^{-1}y^{-1} with mean of 171 MJmmha-^{1}h^{-1}yr^{-1} and standard deviation of 1.9 (Figure 3)

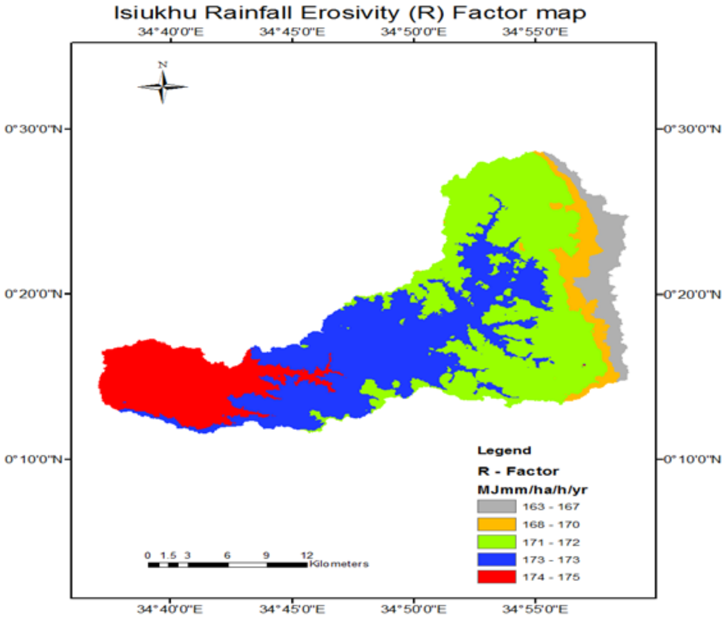

Figure 3: Isiukhu river catchment R factor map

The spatial distribution of rainfall erosivity factor showed that 30% had 171-172 MJmmha-^{1}h^{-1}yr^{-1}, 50% had 173 MJmmha-^{1}h^{-1}yr^{-1} 10% had 174-175 MJmmha-^{1}h^{-1}yr^{-1} (Table 1). From these results, areas such as Mundoli, Kakamega and Mumias with high rainfall, their R factor values are higher than the mean. Since the greater the intensity and duration of the rain storm, the higher the erosivity (R) Factor, it means erosion potential is area specific.

Table 1: Spatial distribution of R factor

Classification of R Factor MJmmha^{-1}h^{-1}y^{-1}	Area (ha)	Spatial distribution of R Factor (%)
163-167	3,415	5
168-170	3,415	5
171-172	20,490	30
173-173	34,150	50
174-175	6,830	10
Total	68,300	100

3.2 Soil erodibility factor (K)

Soil erodibilty factor (K) map showed that there were nine K factor classes with minimum of 0.4 t h MJ^{-1} mm^{-1} along Nandi escarpment, maximum of 0.73 t h MJ^{-1}mm^{-1} in the lower catchment areas, mean of 0.58 t h MJ^{-1}

mm^{-1} and standard deviation of 0.11 (Figure 4).

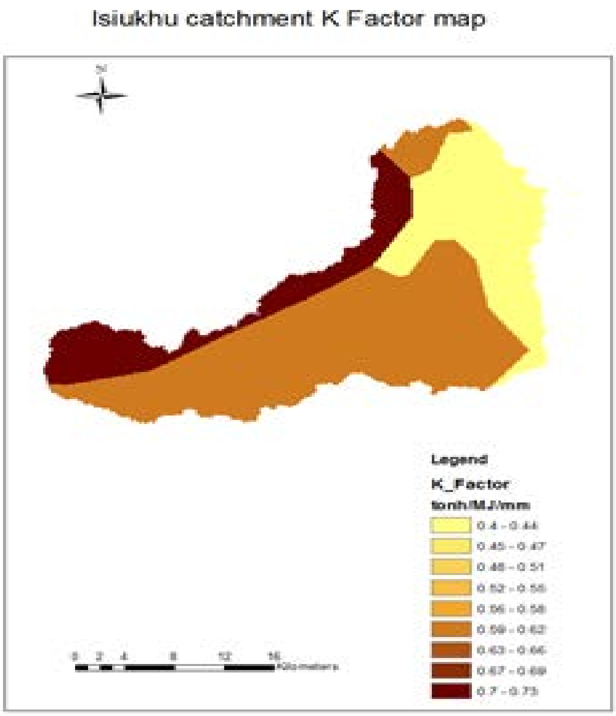

Figure 4: Isiukhu river cathment K factor map

Majority of Isiukhu river catchment has K Factor of 0.59-0.62 thMJ^{-1} mm^{-1} (60%) which is clayey (Sandy clay, silty clay and clay) soils (Table 4.4). Therefore 60% of the catchment is above mean erodibility (K) factor value of 58 t h MJ^{-1} mm^{-1}. Although there is no information on the variation of K with time and season in the study area, the difference in time and location, as well as in management practices would contribute to observed differences in K. The K-factors for tropical soils usually increase when soils are cultivated and vary with soil type, season of the year, and cultural practices [17].

Table 2: Spatial distribution of K factor

Classification of K Factor TonhMJ^{-1}mm^{-1}	**Area (Ha)**	**Spatial distribution of K Factor (%)**
0.4-0.44	3,420	5
0.45-0.47	3,420	5
0.48-0.51	3,420	5
0.52-0.55	3,420	5
0.56-0.58	3,420	5
0.59-0.62	41,000	60
0.63-0.66	3,420	5
0.67-0.69	3,420	5
0.70-0.73	3,420	5
Total	68,300	100

3.3 Slope length and slope steepness factor (LS)

LS factor map showed that LS values ranged from 0 to 1, with the mean of 0.29 and the standard deviation was 0.45 (Figure 5). From the results, the highest elevation was 2,144m and the lowest was 1,317m giving steepness of 827m. The slope length had a minimum of 139m and a maximum of 16,891m. The slopes along Nandi escarpment (source of Isiukhu river) was 246% and decreased to 5% (exit of Isiukhu river). This indicated that there was steep rise from the exit to the source of the river.

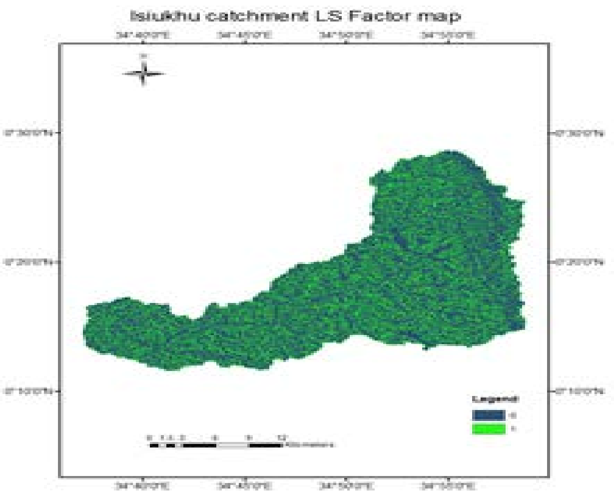

Figure 5: Isiukhu river catchment LS factor map

3.4 Evaluation of change in land use/land cover (C) factor with time in Isiukhu river catchment

Specific objective two aimed at evaluating change in land use/land cover (C factor) with time in Isiukhu river catchment. To achieve this objective, land use/ land cover for 1990, 2000, 2010 and 2015 were computed to evaluate the trend in change based on cover management within the catchment.

3.4.1 Isiukhu river catchment land use/land cover (C factor) 1990

After classification, of the Isiukhu catchment land use as explained in chapter three, 3 main classes were: - forest grass and crop cover. Using the table for C Factor for different land use classes, the values were added in the attribute table of Land Use shapefile in ArcGIS 10.3. Using the C factor as the field during the conversion of feature class to raster the land use shapefile was converted to raster (Figure 6). There were nine land use/land cover (C factor) classes ranging from 0.002 to 0.1. The mean C factor was 0.068 with standard deviation of 0.046. In 1990, the forest cover had a C factor range of 0.002 to 0.035, grass cover had a C factor range of 0.036 to 0.067 and crop cover had a C factor range of 0.068 to 0.1.

Based on C factor spatial distribution classes, 0.002-0.013 covered 8,879ha (13%), 0.014-0.024 covered 7,513ha (11%), 0.025-0.035 covered 7,513ha (11%), 0.036-0.046 covered 7,513ha (11%), 0.047-0.056 covered 6,830ha (10%), 0.057-0.067 covered 7,513ha (11%), 0.068-0.078 covered 7,513ha (11%), 0.079-0.089 covered 7,513ha

(11%) and 0.09-0.1 covered 7,513ha (11%) (Table 3). From the results, the weighted mean ($C_{weighted\ mean}$) for the C factor for Isiukhu river catchment in 1990 was 0.051 and standard deviation (C_{SD}) of 0.029. The areas on the escarpment and near escarpment had low (0.002-0.0133) C factor values because of the forest cover compared to areas far away from the escarpment which had high (0.09-0.1) C factor values because of maize, beans and sugar cane farming. These results for cover management C factor are comparable to other studies done for similar land cover management.

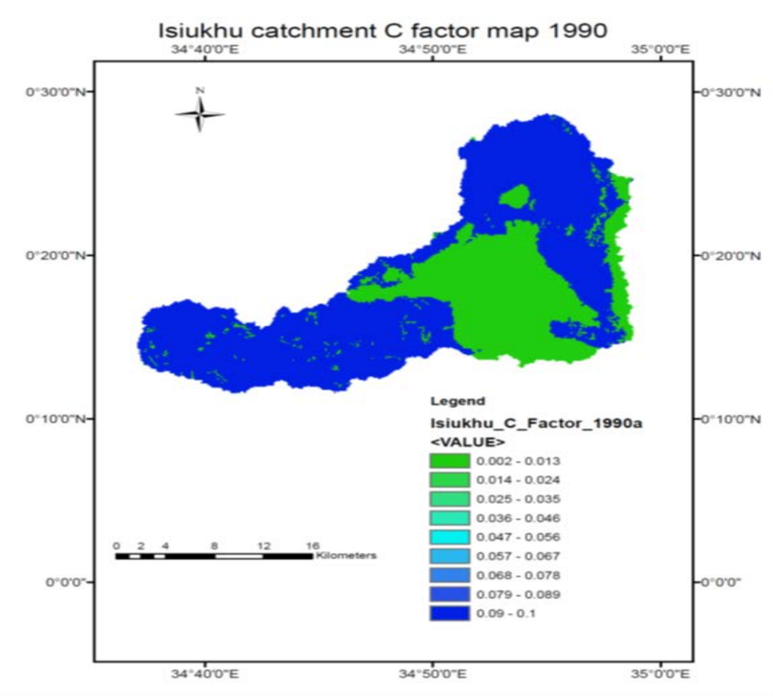

Figure 6: Isiukhu river catchment cover management (C factor) map 1990

Table 3: Isiukhu river catchment C factor 1990 spatial distribution

Isiukhu C Factor classification	**Class mid-point (x)**	**Area coverage (ha) (c)**	**cx**	Percent spatial distribution of C factor
0.002-0.013	0.0075	8,879	66.59	13
0.014-0.024	0.019	7,513	142.75	11
0.025-0.035	0.03	7,513	225.39	11
0.036-0.046	0.041	7,513	308.03	11
0.047-0.056	0.052	6,830	355.16	10
0.057-0.067	0.062	7,513	465.81	11
0.068-0.078	0.073	7,513	548.45	11
0.079-0.089	0.084	7,513	631.09	11
0.09-0.1	0.095	7,513	713.74	11
Total		∑c=68,300	∑cx=3,457.01	100
Weighted mean and standard deviation for C factor 1990		$C_{1990wtdmean} = \frac{3{,}457.01}{68{,}300} = 0.051$		

3.4.2 Isiukhu river catchment cover management C factor 2000

There were nine C factor classes ranging from 0.003 to 0.2 for the year 2000 (Figure 7). The mean C factor was 0.135 with standard deviation of 0.0.093. In this year, the forest cover had a C factor range of 0.003 to 0.069, grass cover had a C factor range of 0.07 to 0.091, settlement had a C factor of 0.092 to 0.112 and crop cover had a C factor range of 0.113 to 0.2. These results showed more encroachments on the forest in terms of farming activities and settlement than the year 1990.

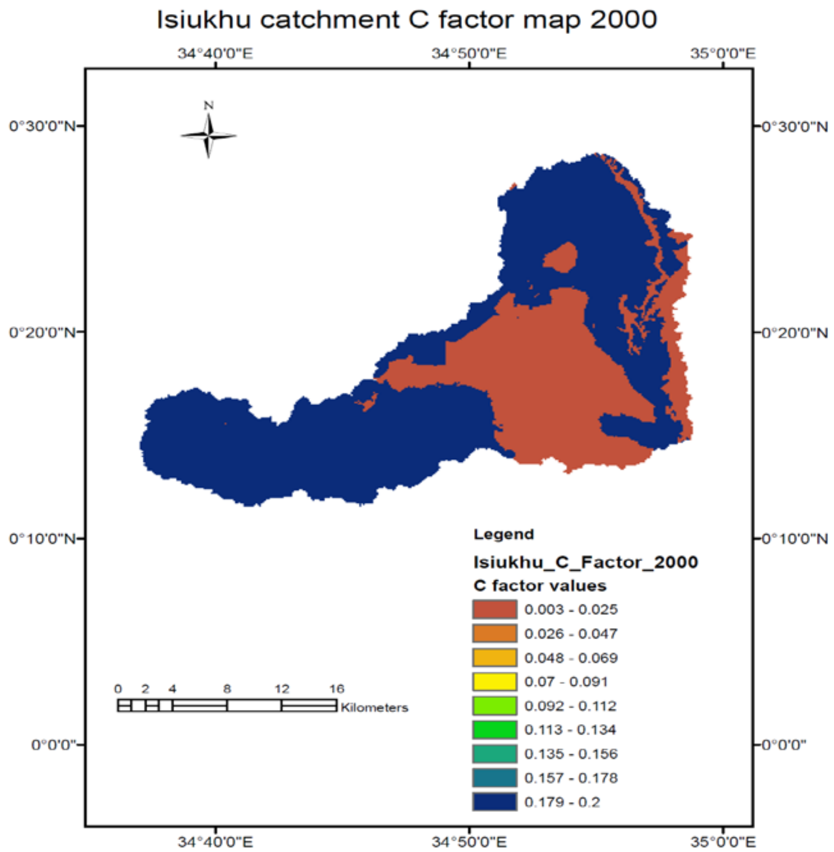

Figure 7: Isiukhu catchment cover management C factor map 2000

Based on C factor spatial distribution classes, 0.003-0.025 covered 8,196ha (12%), 0.026-0.047 covered 7,513ha (11%), 0.048-0.069 covered 7,513ha (11%), 0.07-0.091 covered 7,513ha (11%), 0.092-0.112 covered 7,513ha (11%), 0.113-0.134 covered 7,513ha (11%), 0.135-0.156 covered 7,513ha (11%), 0.157-0.178 covered 7,513ha (11%) and 0.179-0.2 covered 7,513ha (11%) (Table 4).

From the results, the weighted mean ($C_{weighted\ mean}$) of C factor of isiukhu river catchment in 2000 was 0.1 and standard deviation (C_{SD}) of 0.058. After ten years (1990-2000), areas on the escarpment and near escarpment had low (0.003- 0.025) C factor values showing that cover management of Isiukhu river catchment had reduced within 10 years from minimum of 0.002 to 0.003, maximum of 0.1 to 0.2. This could have been due encroachment by communities within and nearby the catchment.

Table 4: Isiukhu river catchment spatial distribution of C factor 2000

Isiukhu C Factor classification	**Class mid-point (x)**	**Area coverage (ha) (c)**	**cx**	**Percent spatial distribution of C Factor**
0.003-0.025	0.014	8,196	114.744	12
0.026-0.047	0.0365	7,513	274.225	11
0.048-0.069	0.0585	7,513	439.511	11
0.07-0.091	0.0805	7,513	604.797	11
0.092-0.112	0.102	6,830	696.66	11
0.113-0.134	0.1235	7,513	927.86	11
0.135-0.156	0.1455	7,513	1,093.14	11
0.157-0.178	0.1675	7,513	1,258.43	11
0.179-0.2	0.1895	7,513	1,423.71	11
Total		∑c=68,300	∑cx=6833.077	100
Weighted mean and standard deviation for C factor 2000		$C_{2000wtdmean} = \frac{6,833.077}{68,300} = 0.100$		

3.4.3 *Isiukhu river catchment cover management C factor 2010*

There were nine C factor classes ranging from 0.004 to 0.3 for the year 2010 (Figure 8). The mean C factor was 0.209 with standard deviation of 0.0.137. In this year, the forest cover had a C factor range of 0.004 to 0.103, grass cover had a C factor range of 0.104 to 0.168, settlement had a c factor range of 0.169 to 0.201 and crop cover had a C factor range of 0.202 to 0.3. These results showed more encroachments on the forest in terms of farming activities and settlement than the year 2000. There were minimal efforts by farmers in conservation activities which must have led to frequent landslides in Khuvasali village within the catchment.

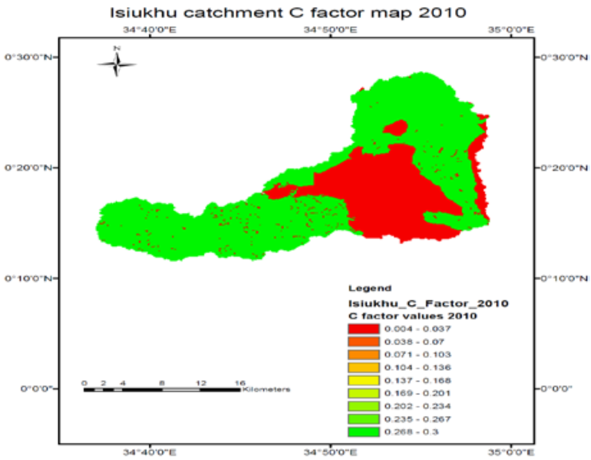

Figure 8: Isiukhu catchment C factor map 2010

Based on C factor spatial distribution classes, 0.004-0.03 covered 8,196ha (12%), 0.038-0.07 covered 7,513ha (11%), 0.071-0.103 covered 7,513ha (11%), 0.104-0.136 covered 7,513ha (11%), 0.137-0.168 covered 7,513ha

(11%), 0.169-0.201 covered 7,513ha (11%), 0.202-0.234 covered 7,513ha (11%), 0.235-0.267 covered 7,513ha (11%) and 0.268-0.3 covered 7,513ha (11%) (Table4.9).

From the results, the weighted mean ($C_{\text{weighted mean}}$) C factor for Isiukhu river catchment in 2010 was 0.151 with standard deviation of 0.088. After twenty years (1990-2010), areas on the escarpment and near escarpment had low (0.004-0.03) C factor values showing that cover management of Isiukhu river catchment had reduced within 20 years from minimum of 0.002 to 0.004, maximum of 0.1 to 0.3 and mean of 0.068 to 0.209. This indicates that cover management of Isiukhu river catchment continued deteriorating with time.

Table 5: Isiukhu river catchment spatial distribution of C factor 2010

Isiukhu C Factor classification	Classification mid-point (x)	Area coverage (ha) (c)	cx	Percent spatial distribution of C Factor
0.004-0.03	0.017	8,196	139.332	12
0.038-0.07	0.073	7,513	405.702	11
0.071-0.103	0.087	7,513	653.631	11
0.104-0.136	0.12	7,513	901.56	11
0.137-0.168	0.1525	7,513	1,145.733	11
0.169-0.201	0.185	7,513	1,389.905	11
0.202-0.234	0.218	7,513	1,637.834	11
0.235-0.267	0.251	7,513	1,885.763	11
0.268-0.3	0.284	7,513	2133.692	11
Total		68,300	10,293.152	100
Weighted mean and standard deviation of C factor 2010			$C_{2010\,wtdmean} = \frac{10,293.152}{68,300} = 0.151$	Percent spatial distribution of C Factor

3.4.4 Isiukhu river catchment cover management C factor 2015

There were nine C factor classes ranging from 0.02 to 0.5 for the year 2015. The mean C Factor was 0.373 with standard deviation of 0.212 (Figure 9). There were 3 main land use/land cover classes were: - Agriculture, Forest and Woodland. In this year, the forest cover had a C factor range of 0.02 to 0.127, woodland had a C factor range of 0.128 to 0.287, and agriculture had a C factor range of 0.288 to 0.5. These results showed more encroachments on the forest in terms of farming activities and settlement than the year 2010.

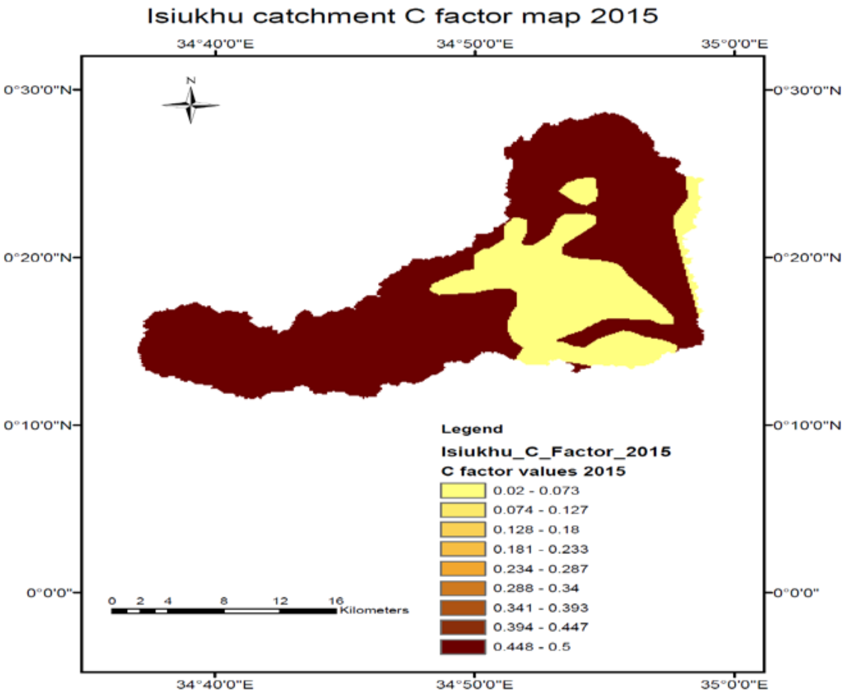

Figure 9: Isiukhu catchment C factor map 2015

In 2015 land use/land cover in Isiukhu river catchment showed agriculture (maize, beans sugar cane and sweet potatoes) with highest C factor values of 0.46-0.5 and forest having lowest values of 0.02-0.07 (Table 6)

Table 6: Isiukhu catchment C factor 2015

Object ID	Land Use Classification	Land Use Number	Land Use	Composition	C Factor
1	440	11	Agriculture	Maize. Beans, sugar cane, sweet potatoes	0.46 – 0.5
2	613	1	Forest	Exotic trees, indigenous trees, natural vegetation	0.02 – 0.07
3	619	1	Forest	Exotic trees, indigenous trees, natural vegetation	0.02 – 0.07
4	629	1	Forest	Exotic trees, indigenous trees, natural vegetation	0.02 - 0.07
5	642	2	Woodland	Forest and wood	0.08 – 0.13
6	654	1	Forest	Exotic trees, indigenous trees, natural vegetation	0.02 – 0.07
7	657	2	woodland	Forest and wood	0.08 – 0.13
8	660	11	Agriculture	Maize. Beans, sugar cane, sweet potatoes	0.46 - 0.5

Based on C factor spatial distribution classes, 0.02-0.073 covered 10,245ha (15%), 0.074-0.127 covered 6,830ha (10%), 0.128-0.18 covered 3,415ha (5%), 0.181-0.233 covered 1,366ha (2%), 0.234-0.287 covered 683ha (1%), 0.288-0.34 covered 683ha (1%), 0.341-0.393 covered 683ha (1%), 0.394-0.447 covered 3,415ha (5%) and 0.448-0.5 covered 40,980ha (60%) (Table 7).

From the results, the weighted mean (Cweighted mean) C factor for Isiukhu river catchment in 2015 was 0.344 with standard deviation of 0.179. After 25 years, areas on the escarpment and near escarpment had low (0.02-0.233) C factor values because of the forest cover compared to areas far away from the escarpment which had high (0.234-0.5) C factor values because of maize, beans and sugar cane farming. These results for cover management C factor are comparable to other studies done for similar crop cover management.

Table 7: Spatial distribution of Isiukhu catchment C factor 2015

Isiukhu C Factor classification	Classification mid-point (x)	Area coverage (ha) (c)	cx	Percent spatial distribution of C factor
0.02-0.073	0.0465	10,245	476.393	15
0.074-0.127	0.1005	6,830	686.415	10
0.128-0.18	0.154	3,415	525.91	5
0.181-0.233	0.207	1,366	282.762	2
0.234-0.287	0.2605	683	177.922	1
0.288-0.34	0.314	683	214.462	1
0.341-0.393	0.367	683	250.661	1
0.394-0.447	0.4205	3,415	1,436.008	5
0.448-0.5	0.474	40,980	19,424.52	60
Total		68,300	23,475.053	100
Weighted mean and standard deviation of C factor 2015			$C_{2015wtdmean} = \frac{23,475.053}{68,300} = 0.344$	Percent spatial distribution of C factor

3.5 Isiukhu river catchment soil erosion control support practice (P) factor

To compute P Factor, Isiukhu raw DEM map (Figure 4.1), Fill sink Isiukhu DEM map, Flow direction Isiukhu DEM map, Isiukhu Flow accumulation DEM map and Isiukhu slope_degree map were overlaid in ArcGIS 10.3. Applying Falls equation 5 in ArcMap raster calculator:

$$P = Flowaccumulation \times 0.45249^{0.6} + 0.01745 \times Slope\_\deg ree$$

where; P is the soil erosion conrol practice factor; Flow accumulation = Study area DEM flow accumulation; Slope_degree = Study area DEM slope in degrees

The results of soil erosion control support practice (P) factor map are shown in figure 4.16. P factor values are dependent on various soil and water conservation measures such as bench terraces, fanya juu terraces, trash lines, grass strips and other related conservation measures. The values range from 0 to 1, high values indicate no effective conservation measures.

The lowest P factor value was 0 while the highest value was 1 (Figure 10). The mean value was 0.29 and standard deviation of 0.45. It could be observed from the results that there were no major classification of P factor which implied that no various soil erosion control support practices have been undertaken by the community. P factor represents soil erosion control measures such as various types of terraces, trash lines, contour farming, mulching, tree planting among others.

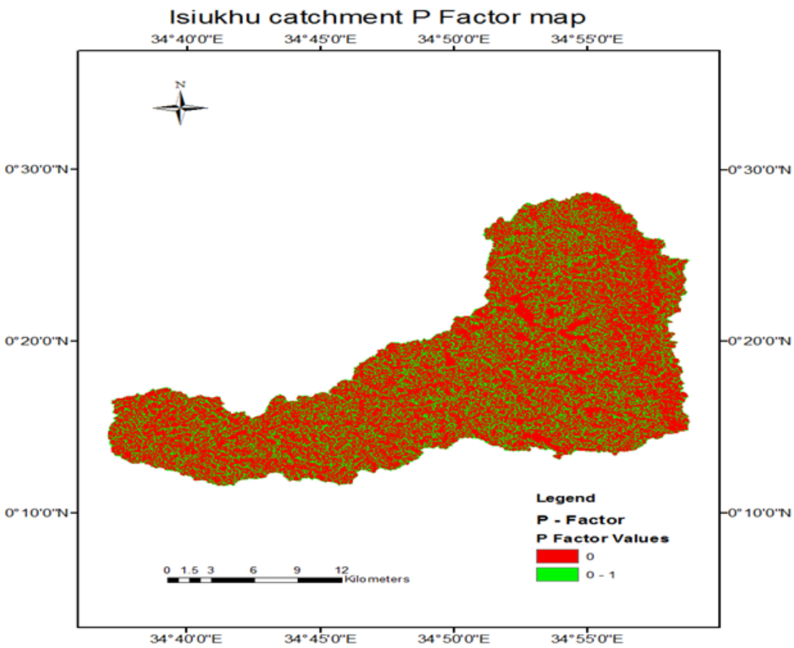

Figure 10: Isiukhu river catchment P factor map

3.6 Determination of actual soil erosion risk with change in land use/land cover in 1990, 2000, 2010 and 2015

To compute soil erosion risk, all RUSLE model factors (R, K, LS, C and P) were combined in ArcGIS 10.3. C factor maps for 1990, 2000, 2010 and 2015 were used in RUSLE model to determine actual soil erosion risk for each specific year with change in land use/land cover.

3.4.2 Determination of actual soil erosion risk ($RUSLE_{actual}$) using C factor of 1990

To determine actual soil erosion risk for 1990 ($RUSLE_{1990}$), R, K, LS and P factor maps were overlaid with C factor map of 1990 in ArcGIS 10.3 i.e. $RUSLE_{1990}= RKLSC_{1990}P$

The spatial distribution of the actual soil erosion risk showed that 0-6 t/ha/y covered 11%, 7-7 t/ha/y covered 44%, 11-12 t/ha/y covered 29% and 13-13 t/ha/y covered 17% (Figure 4.20). The results indicated that there were five classes of actual soil erosion risk in 1990 with minimum of 0 t/ha/y and maximum of 13 t/ha/y. The mean was 2 t/ha/y indicating standard deviation of 4 (Figure 11). These results showed that in 1990, more than 85% of Isiukhu river catchment had soil erosion risk within tolerance limit 12t/ha/y for Kenyan soils (Thomas, 1997). Compared with potential soil erosion risk which had more than 93% above soil erosion tolerance limit, land use/land cover in 1990 of C factor 0.002 to 0.1 played a great role in reducing soil erosion risk.

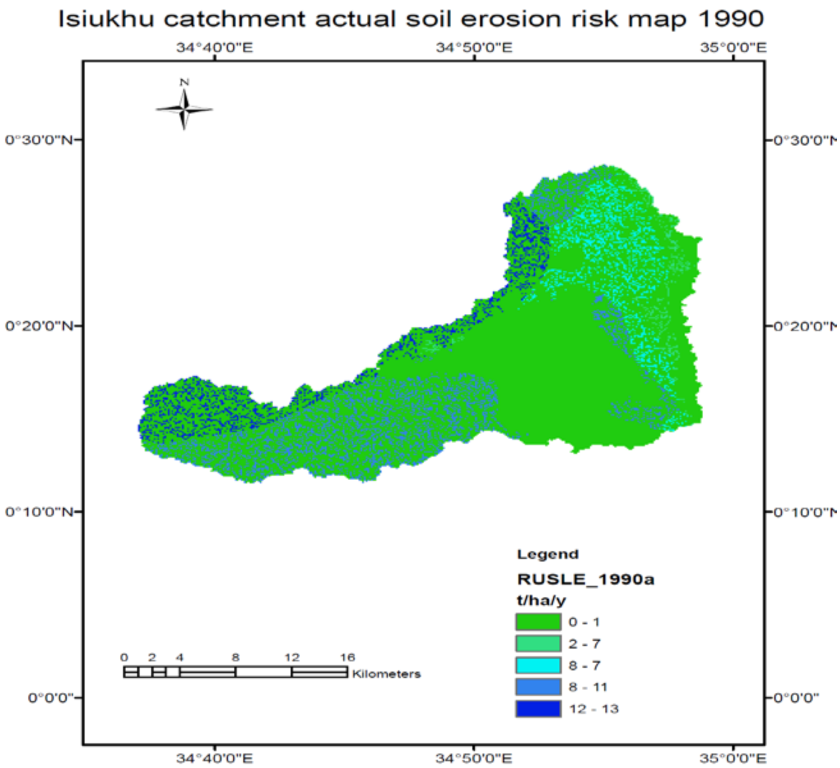

Figure 11: Isiukhu catchment actual soil erosion risk map 1990

Spatial distribution of actual soil erosion risk 1990 for Isiukhu catchment showed 0-1 t/ha/y covered 7,513 ha (11%), 2-7 t/ha/y covered 28,686ha (42%), 8-9 t/ha/y covered 683ha (1%), 10-11 t/ha/y covered 19,807ha (29%) and 12-13 t/ha/y covered 11,611ha (17%) (Table 8). The weighted mean ($RUSLE_{weighted\ mean}$) for Isiukhu river catchment for 1990 was 7.2 t/ha/y with standard deviation of 3.994. Therefore in 1990, the weighted mean for soil erosion risk ($RUSLE_{weighted\ mean}$) was below tolerance limit of 12 t/ha/y).

3.6.2 Estimation of Isiukhu catchment actual soil erosion risk using C factor of 2000

To determine actual soil erosion risk for 2000 ($RUSLE_{2000}$), R, K, LS and P factor maps were overlaid with C factor map of 2000 in ArcGIS 10.3 i.e. $RUSLE_{2000}= RKLSC_{2000}P$

The spatial distribution of the actual soil erosion risk showed that 0-2 t/ha/y covered 6%, 3-13 t/ha/y covered 20%, 14-20t/ha/y covered 27%, 21-23 t/ha/y covered 21 and 24-26 t/ha/y covered 26% (Figure 4.22). There were five classes of actual soil erosion risk in 2000 with minimum of 0 t/ha/y and maximum of 26 t/ha/y. The mean was 4 t/ha/y with standard deviation of 8 (Figure 4.23). These results showed that in 2000, 74% of Isiukhu catchment was having medium to high soil erosion risk (14-26 t/ha/y). Compared with actual soil erosion risk of 1990 which had more than 85% within soil erosion tolerance limit, land use/land cover in 2000 of C factor 0.003 to 0.2 had increased soil erosion risk by about 10% indicating worse land use/land cover management.

Table 8: Spatial distribution of soil erosion in 1990

Classification of erosion rates (t ha^{-1} y^{-1})	**Classification mid-point (x)**	**Area coverage (ha) (c)**	**cx**	**Percent spatial distribution**
0-1	0.5	7,513	3,756.5	11
2-7	4.5	28,686	129,087	42
8-9	8.5	683	5,805.5	01
10-11	10.5	19,807	207,973.5	29
12-13	12.5	11,611	145,137.5	17
Total		68,300	491,760	100
Weighted mean and standard deviation of actual soil erosion risk 1990			$RUSLE_{1990\,wtdmean} = \frac{491760}{68,300} = 7.2$	

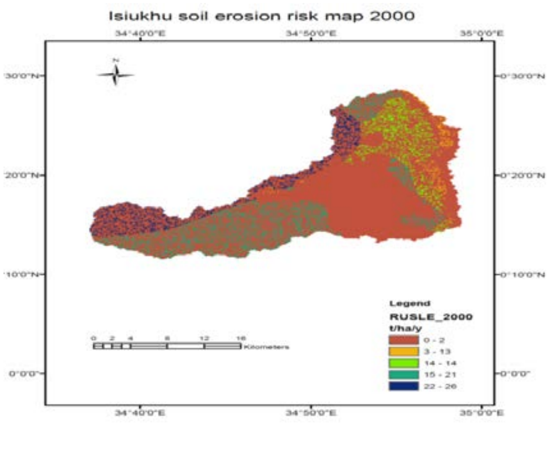

Figure 12: Soil erosion risk map 2000

Spatial distribution of actual soil erosion risk 2000 for Isiukhu catchment showed 0-2 t/ha/y covered 4,098ha (6%), 3-13 t/ha/y covered 16,392ha (20%), 14-20 t/ha/y covered 18,441ha (27%), 21-23 t/ha/y covered 14,343ha (21%) and 24-26 t/ha/y covered 17,758ha (26%) (Table 4.13). The weighted mean (RUSLEweighted mean) for Isiukhu river catchment for 2000 was 17.69 t/ha/y with standard deviation of 6.682. Therefore in 2000, the weighted mean for soil erosion risk ($RUSLE_{weighted\ mean}$) was above tolerance limit of 12 t/ha/y) by 5.69 t/ha/y. compared with 1990, soil erosion risk was higher by 10.49 t/ha/y (17.69-7.2).

Table 9: Spatial distribution of soil erosion risk 2000

Classification of erosion rates (t ha^{-1} y^{-1})	**Classification mid-point (x)**	**Area (ha) c**	**cx**	**Percent spatial distribution**
0-2	1	4,098	4,098	06
3-13	8	16,392	131,136	20
14-20	17	18,441	313,497	27
21-23	22	14,343	315,546	21
24-26	25	17,758	443,950	26
Total		**68,300**	**1,208,227**	**100**
Weighted mean and standard deviation of actual soil erosion risk 2000			$RUSLE_{2000wtdmean} = \frac{1,208,227}{68,300} = 17.69$	

3.6.3 Estimation of Isiukhu catchment actual soil erosion risk using C factor of 2010

To determine actual soil erosion risk for 2010 ($RUSLE_{2010}$), R, K, LS and P factor maps were overlaid with C factor map of 2010 in ArcGIS 10.3 i.e. $RUSLE_{2010}= RKLSC_{2010}P$

The spatial distribution of the actual soil erosion risk showed that 0-26 t/ha/y covered 2%, 27-41 t/ha/y covered 52%, 42-42 t/ha/y covered 28%, 43-48 t/ha/y covered 1% and 49-51 t/ha/y covered 17% (Figure 4.24). There were five classes of actual soil erosion risk in 2010 with minimum of 0 t/ha/y and maximum of 51 t/ha/y. The mean was 8 t/ha/y with standard deviation of 16 (Figure 13). These results showed that in 2010, 98% of Isiukhu river catchment was having high to very high soil erosion risk (27-51 t/ha/y). Compared with actual soil erosion risk of 2000 which had 74% of medium to high, land use/land cover in 2000 of C factor 0.03 to 0.3 had increased soil erosion risk by about 20% indicating worse land use/land cover management.

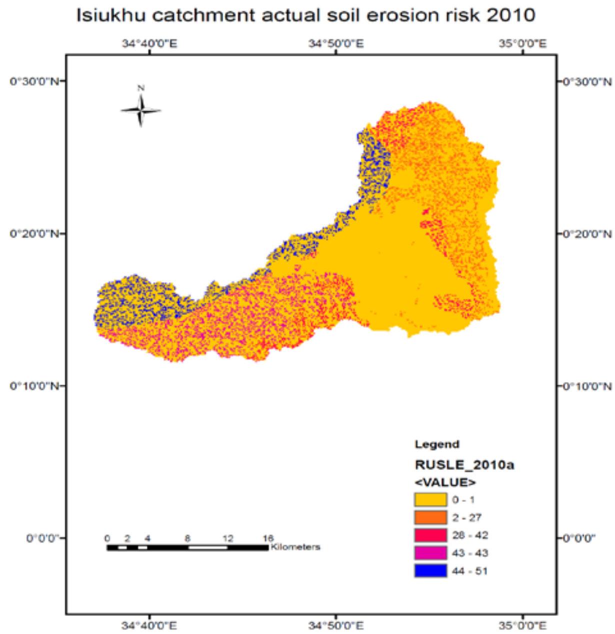

Figure 13: Soil erosion risk map 2010

Spatial distribution of actual soil erosion risk 2010 for Isiukhu catchment showed 0-1 t/ha/y covered 1,366ha (2%), 2-27 t/ha/y covered 35,516ha (52%), 28-42 t/ha/y covered 19,124ha (28%), 43-43t/ha/y covered 683ha (1%) and 44-51 t/ha/y covered 11,611ha (17%) (Table 10). The weighted mean ($RUSLE_{weighted\ mean}$) for Isiukhu river catchment for 2010 was 25.855 t/ha/y with standard deviation of 13.635. Therefore in 2010, the weighted mean for soil erosion risk ($RUSLE_{weighted\ mean}$) was above tolerance limit of 12 t/ha/y) by 13.855 t/ha/y. compared with 2000, soil erosion risk was higher by 8.165 t/ha/y (25.855-17.69).

Table 10: Spatial distribution of soil erosion risk 2010

Classification of erosion rates ($t\ ha^{-1}\ y^{-1}$)	Classification mid-point (x)	Area coverage (ha) (c)	cx	% spatial distribution
0-1	0.5	1,366	683	02
2-27	14.5	35,516	514,982	52
28-42	35	19,124	669,340	28
43-43	43	683	29,369	01
44-51	47.5	11,611	551,522.5	17
Total		68,300	1,765,896.5	100
Weighted mean and standard deviation of actual soil erosion risk 2010			$RUSLE_{2010wtdmean} = \frac{1,765,896.5}{68,300} = 25.855$	

3.6.4 Estimation of Isiukhu catchment actual soil erosion risk using C factor of 2015

To determine soil erosion risk for 2015 ($RUSLE_{2015}$), R, K, LS and P factor maps were overlaid with C factor map of 2015 in ArcGIS 10.3 i.e. $RUSLE_{2015}= RKLSC_{2015}P$

The spatial distribution of the actual soil erosion risk showed that 0-3 t/ha/y covered 2%, 4-34 t/ha/y covered 5%, 35-52 t/ha/y covered 45%, 53-53 t/ha/y covered 21% and 54-64 t/ha/y covered 27%. (Figure 4.26). There were five classes of actual soil erosion risk in 2015 with minimum of 0 t/ha/y and maximum of 64 t/ha/y. The mean was 11 t/ha/y with standard deviation of 21 (Figure 14). These results showed that in 2015, over 98% of Isiukhu river catchment was having high to very high soil erosion risk (35-64 t/ha/y). Compared with actual soil erosion risk of 2010 land use/land cover in 2015 of C factor 0.02 to 0.5 had increased soil erosion risk by over 20% indicating worse land use/land cover management

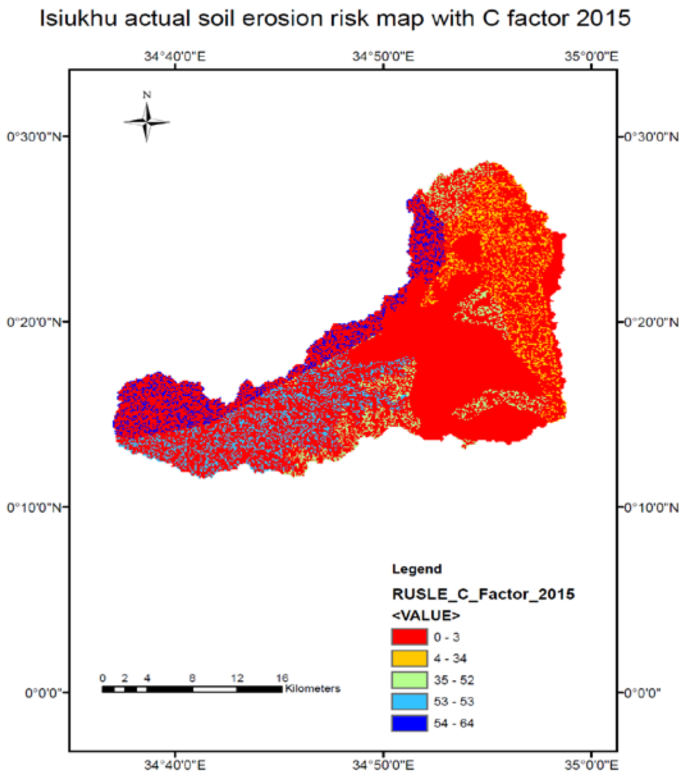

Figure 14: Soil erosion risk map 2015

Spatial distribution of actual soil erosion risk 2015 for Isiukhu catchment showed 0-12 t/ha/y covered 10,245ha (15%), 13-34 t/ha/y covered 26,637ha (39%), 35-51 t/ha/y covered 19,124ha (28%), 52-53t/ha/y covered 683ha (1%) and 54-64 t/ha/y covered 11,611ha (17%) (Table 12).

The weighted mean ($RUSLE_{weighted\ mean}$) for Isiukhu river catchment for 2015 was 32.660t/ha/y with standard deviation of 16.931. Therefore in 2015, the weighted mean for soil erosion risk ($RUSLE_{weighted\ mean}$) was above tolerance limit of 12 t/ha/y) by 20.660 t/ha/y. compared with 2010, soil erosion risk was higher by 6.805 t/ha/y (32.660-25.855).

Table 11: Spatial distribution of soil erosion 2015

Classification of erosion risk ($tha^{-1}y^{-1}$)	Classification mid-point (x)	Area coverage (ha) (c)	cx	% spatial distribution
0 - 12	6	10,245	61,470	15
13 - 34	23.5	26,637	625,969.5	39
35 - 51	43	19,124	822,332	28
52 - 53	52.5	683	35,857.5	01
54 - 64	59	11,611	685,049	17
Total		68,300	2,230,677.5	100
Wtd mean and SD of actual soil erosion risk 2015			$RUSLE_{2015wtdmean} = \frac{2,230,677.5}{68,300} = 32.660$	

4. Conclusion

The evaluation of land use/land cover (LULC) change with time in assessing soil erosion risk using RUSLE model in ArcGIS 10.3 with its other factors namely rainfall erosivity (R); soil erodibility (K); slope length and slope steepness (LS) and soil erosion control support practice (P) are studied. The results of Isiukhu river catchment suggest that LULC has changed drastically from 1990 to 2015. This change subsequently affected soil erosion risk in the catchment and its environs. In 1990, the weighted mean ($C_{weighted\ mean}$) for the C factor was 0.051 1 with corresponding soil erosion risk ($RUSLE_{weighted\ mean}$) of 7.2 t/ha/y. In 2000, the weighted mean ($C_{weighted\ mean}$) for the C factor was 0.1 with corresponding soil erosion risk ($RUSLE_{weighted\ mean}$) of 17.69 t/ha/. In 2010, the weighted mean ($C_{weighted\ mean}$) for the C factor was 0.151 with corresponding soil erosion risk ($RUSLE_{weighted\ mean}$) of 25.855 t/ha. In 2015, the weighted mean ($C_{weighted\ mean}$) for the C factor was 0.344 with corresponding soil erosion risk ($RUSLE_{weighted\ mean}$) of 32.66 t/ha. The study concludes that change in Land use/land cover in Isiukhu river catchment has influenced soil erosion risk. The study discourages indiscriminate felling of trees, mono-cropping, over grazing, ploughing up and down the slope and other anthropogenic activities that expose ground surface for high surface run-off.

5. Recommendation

The study recommends an-all inclusive approach to environmental management that would encourage afforestation, multiple cropping to improve on proper land use/land cover and implementation of both physical and biological soil erosion control support practices to mitigate land degradation.

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